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Development of Reflective Coatings for BEUV Lithography

Presented by L. Sjmaenok

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Agenda

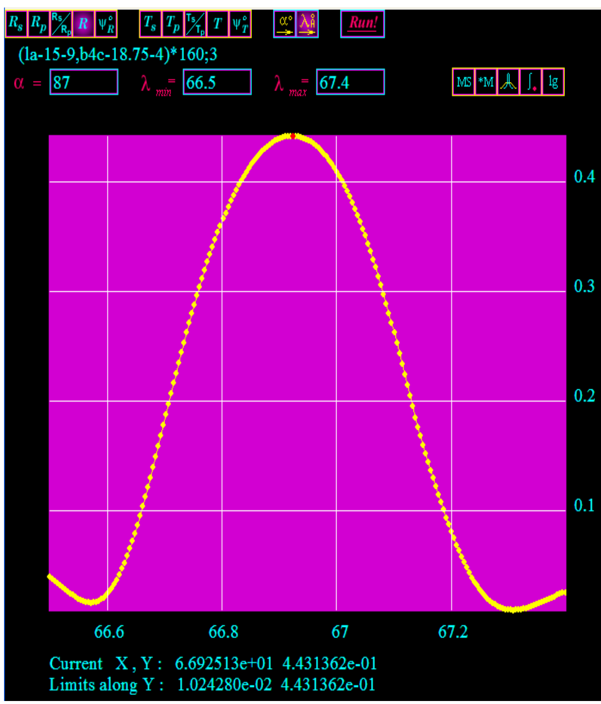
- Calculated reflectivity near 6.7 nm
- Fabrication of $La/B_4C(B_9C)$ MLMs for 6.7 nm
- Reflectivity measurements and experimental data
- Study of internal structure of La/B_4C MLMs
- Anti-diffusive barrier layers in $La/B_4C(B_9C)$ MLMs
- Current tasks

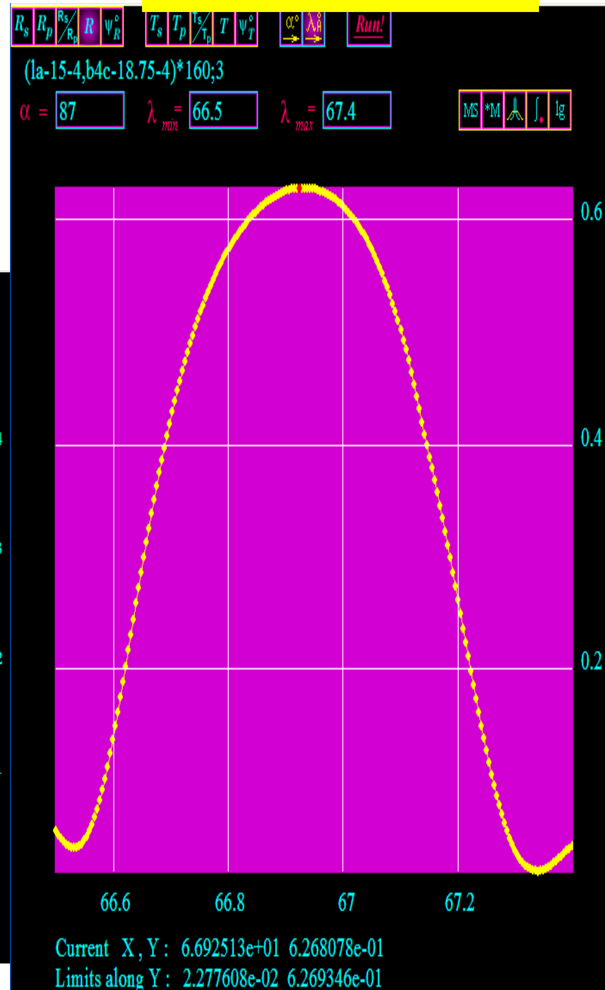
Calculated reflectivity contours $R(\lambda)$ for La/B_4C structures

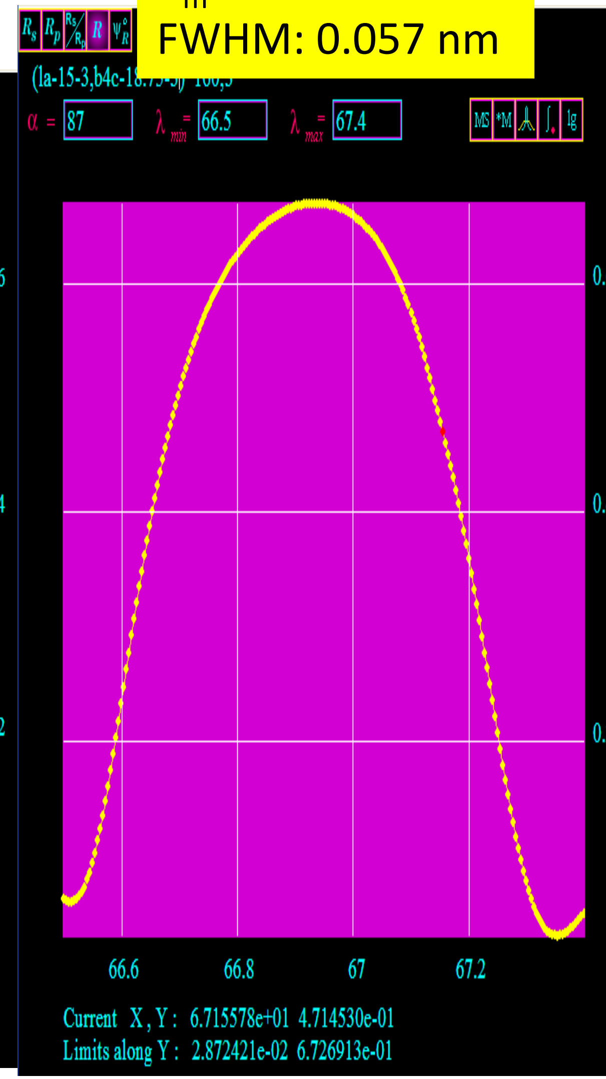
La-on-B_4C: 0.9 nm
B_4C-on-La: 0.4 nm
R_m: 44.3%
FWHM: 0.040 nm

0.4 nm - 0.4 nm
R_m: 62.7%
FWHM: 0.052 nm

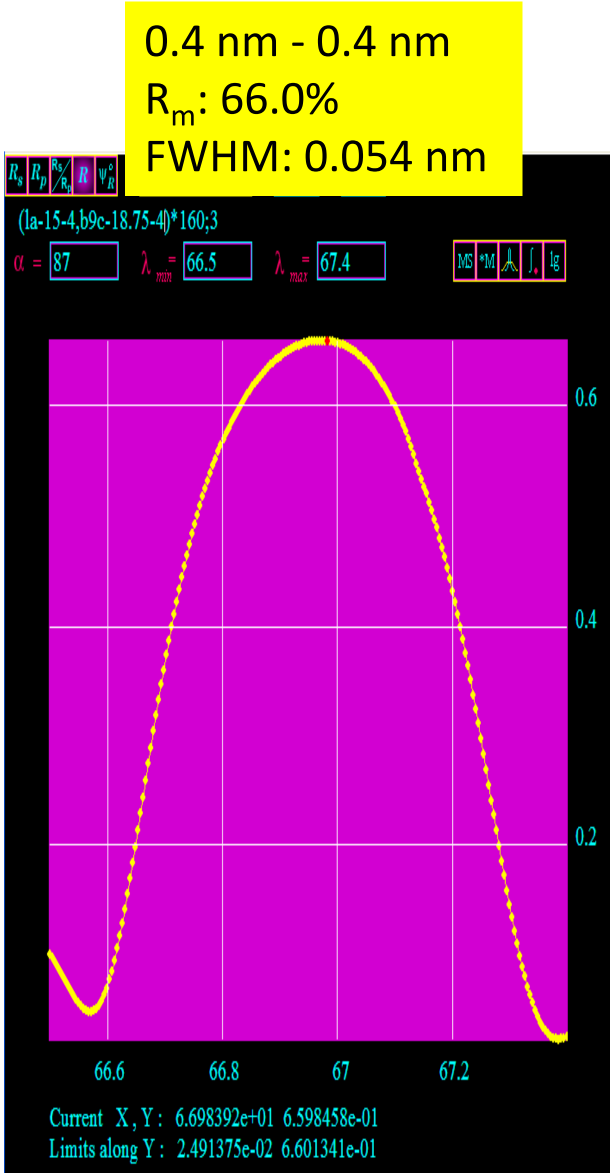
0.3 nm - 0.3 nm
R_m: 67.2%
FWHM: 0.057 nm

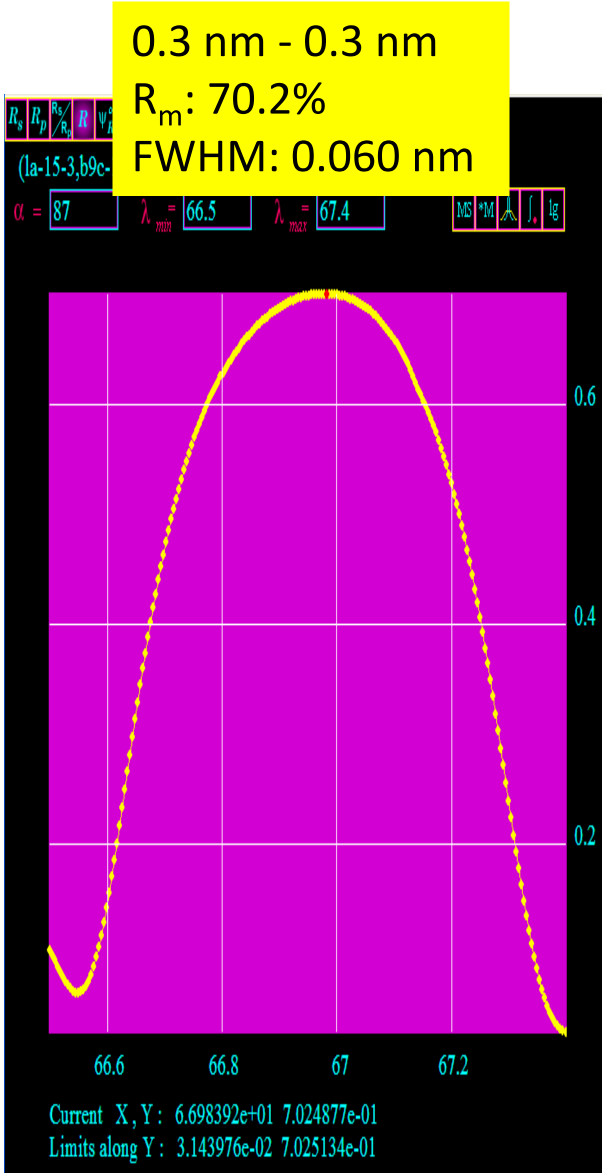






Calculated reflectivity contours $R(\lambda)$ for La/B_9C structures



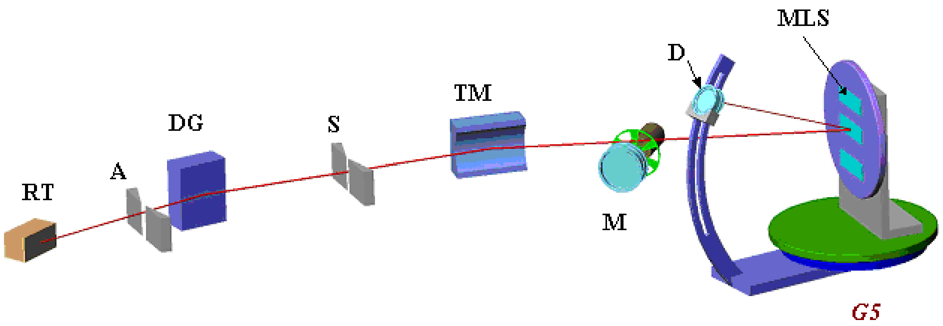


La/B_4C(B_9C) growing process

- Substrate: **Si**, $\sigma \approx$ **0.3** nm
- Ar-pressure: **$9 \cdot 10^{-4}$** mbar
  background: **$<10^{-6}$** mbar
- **DC** and **RF** sputtering
- Number of sputter sources (materials): **2** and **4**
- Power: **220** and **450** W

Reflectivity measurements

- RT – X-ray tube
- A,S – entrance and exit slits
- G – spherical diffraction grating with:
  R = 6 m (range 0.6-5 nm)
  R = 4 m (range 1.6-9 nm)
  R = 2 m (range 4-50 nm)
- TM – thoroidal mirror
- D, M – master and monitor detectors
- MLM – sample under study
- *G5* – 5-axis goniometer



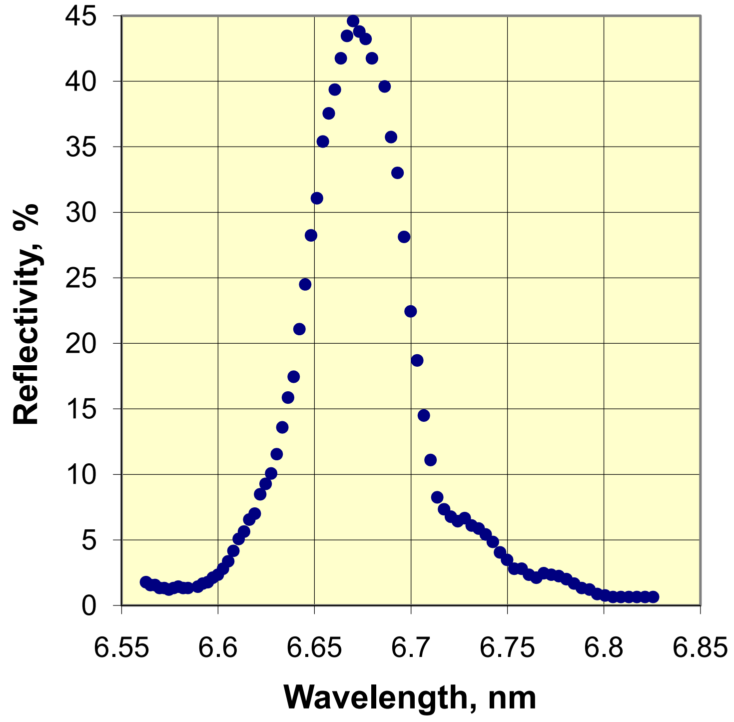
Results of near-normal incidence measurements

MLM		θ_{max} (°)	$\lambda/\Delta\lambda$	R_{max} (%)	R_{id} (%)
La/B_4C	PM680	74.35	126	**>44**	**65**
	A2397	80.61	115.5	33	
	A2408	78.7	122	38	
	A2413	79.66	116	37	
	A2418	77.91	111.5	37	
	A2419	80.45	120	40	
La/B_9C	A2428	72.08	107	**38**	**66**
Ce/B_4C	LVP27	80.6	108	33	**57**
	LVP31	82.88	109	**36**	
	LVP32	77.71	110	35	

The measured reflectivities are at least by 30% lower than the predicted ones

WHY?

Best spectral reflectivity profile obtained by Jan. 2009



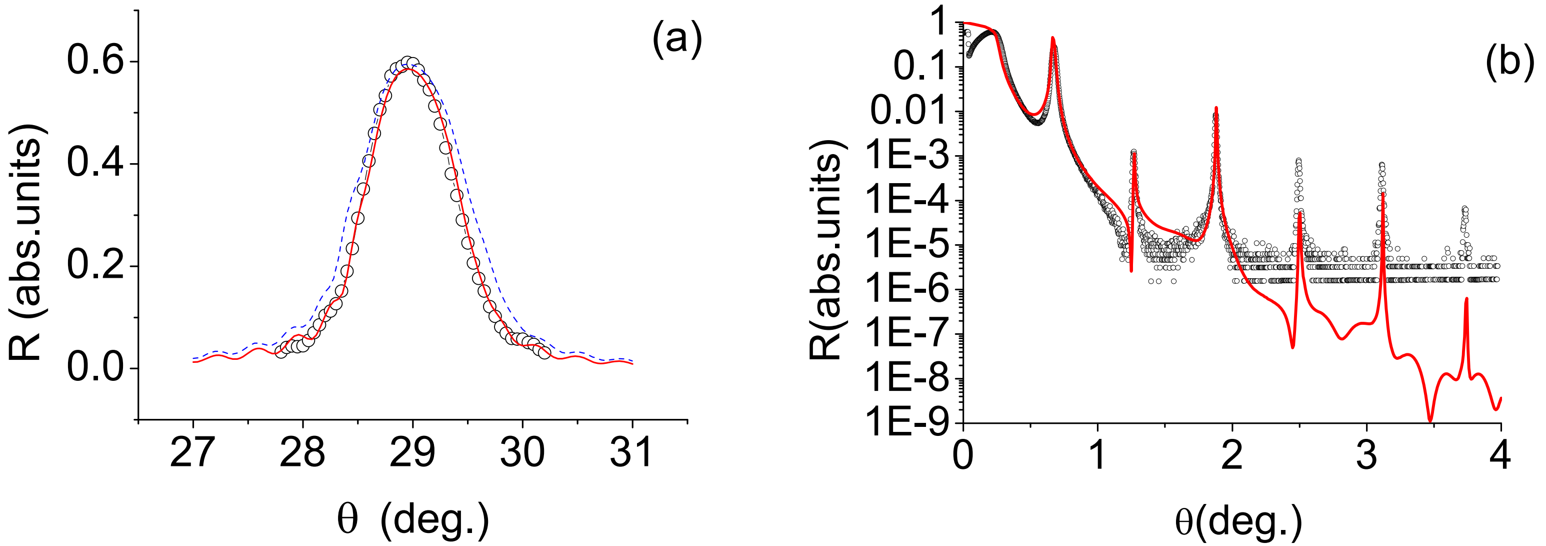
If optical constants of La at λ=6.7 nm are incorrect, large-*d* MLM would exhibit same deviation from theoretical values

MLM		θ_{max} (°)	$\lambda/\Delta\lambda$	R_{exp} (%)	R_{theor} (%)
La/B_4C	A2420	28.95	34	60	60
Ce/B_4C	LVP33	28.82	32	47	49
La/B_9C	A2427	27.06	29	59	64

Reflectivity is close to the theoretical prediction

Reason of the poor reflection – **bad interfaces**

Fitting angular dependencies of reflection for La/B_4C structures



Number of periods N = 150. (a) λ = 6.69 nm; (b) λ = 0.154 nm. Fitting parameters: $\boldsymbol{d}$ **= 7.12 nm,** β **= 0.48,** σ **= 0.47 nm,** ρ_{La} **= 5.5 g/cm³,** ρ_{B4C} **= 1.8 g/cm³**. Blue curve corresponds to “ideal” MLM.

Fitting for λ=0.154 nm is poor in many Bragg peaks.

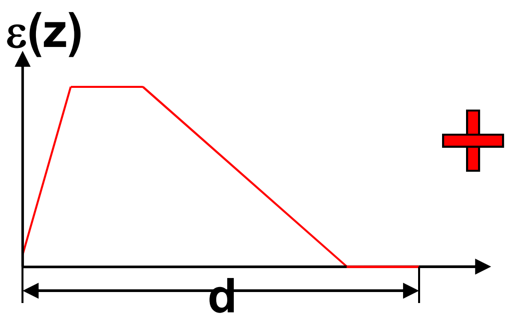
A model with symmetrical interfaces does not work!

Reconstruction of electron density profile with reflection coefficients R_m at λ=0.154 nm in higher orders. If the profile is asymmetric and quantity of La and B_4C materials is close to 1:1, a_m can be neglected.

$$\varepsilon(z) = \varepsilon_0 + \sum_{m=1}^{\infty} a_m \cos(q_m z) + \sum_{m=1}^{\infty} b_m \sin(q_m z), \qquad q_m = 2\pi m / d$$

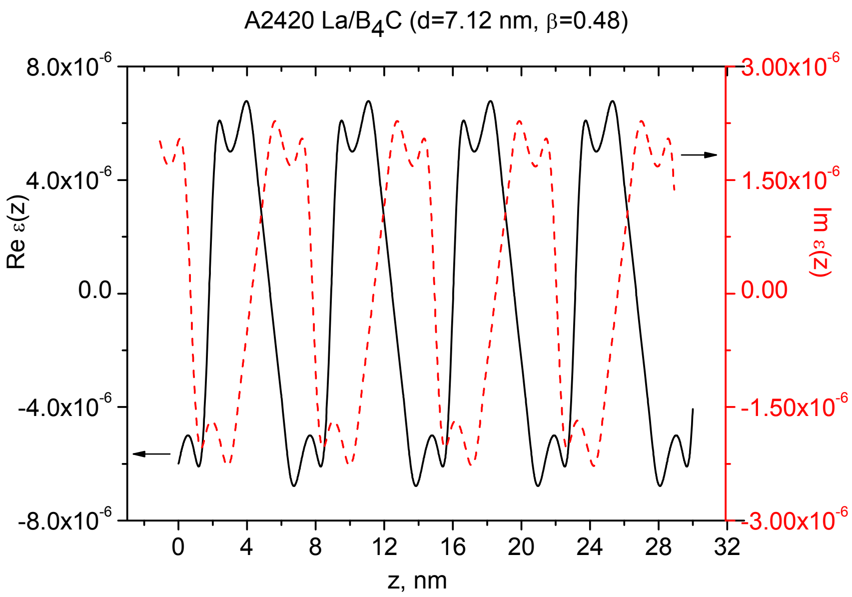
$$\varepsilon(z) = \varepsilon_0 + \left[(\varepsilon_1' - \varepsilon_2') + i(\varepsilon_1'' - \varepsilon_2'')\right]\left\{\sum_{m=1}^{\infty} a_m^{norm} \cos(q_m z) + \sum_{m=1}^{\infty} b_m^{norm} \sin(q_m z)\right\}$$

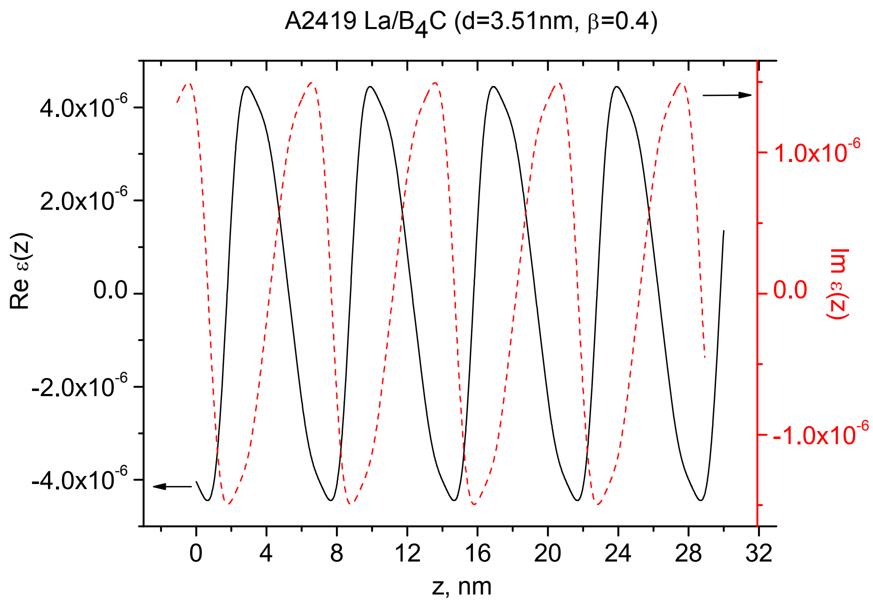
$$R_m = \left[(\varepsilon_1' - \varepsilon_2')^2 + (\varepsilon_1'' - \varepsilon_2'')^2\right]\left(\frac{d}{\lambda}\right)^4\left(\frac{2\pi N}{m}\right)^2\left[\cancel{\left(a_m^{norm}\right)^2} + \left(b_m^{norm}\right)^2\right]$$



+ β = 0.5 = $R_m \leftrightarrow b_m$

Reconstruction results for small-*d* and large-*d* La/B_4C structures

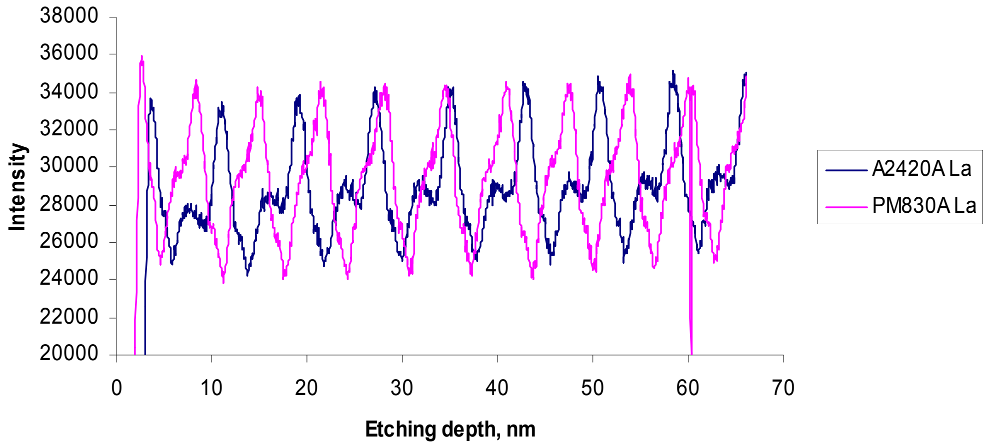


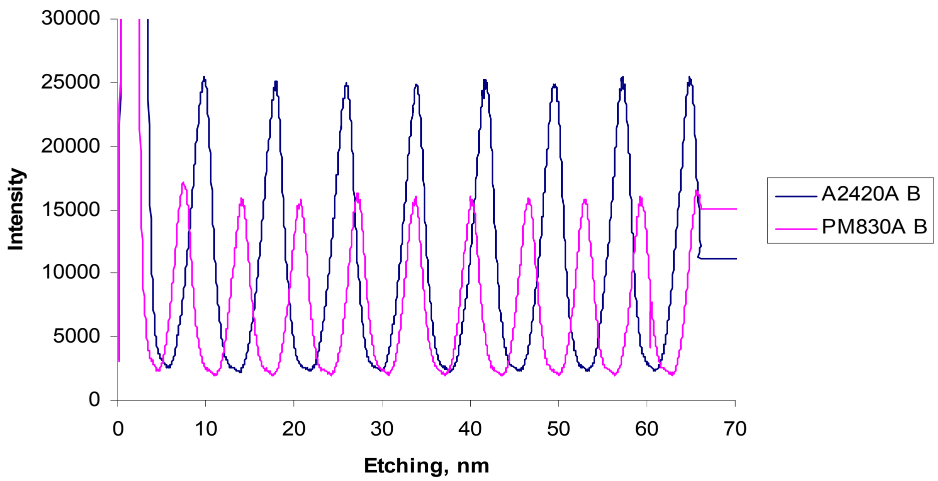


We see that interfaces are strongly asymmetric.

The interface width is about **1 nm** at one side and **2 nm** at the other side and dose not depend on the MLM period.

La and B profiles in La/B_4C measured by SIMS





Lanthanum at the left side of the profiles demonstrates it's implantation into boron films

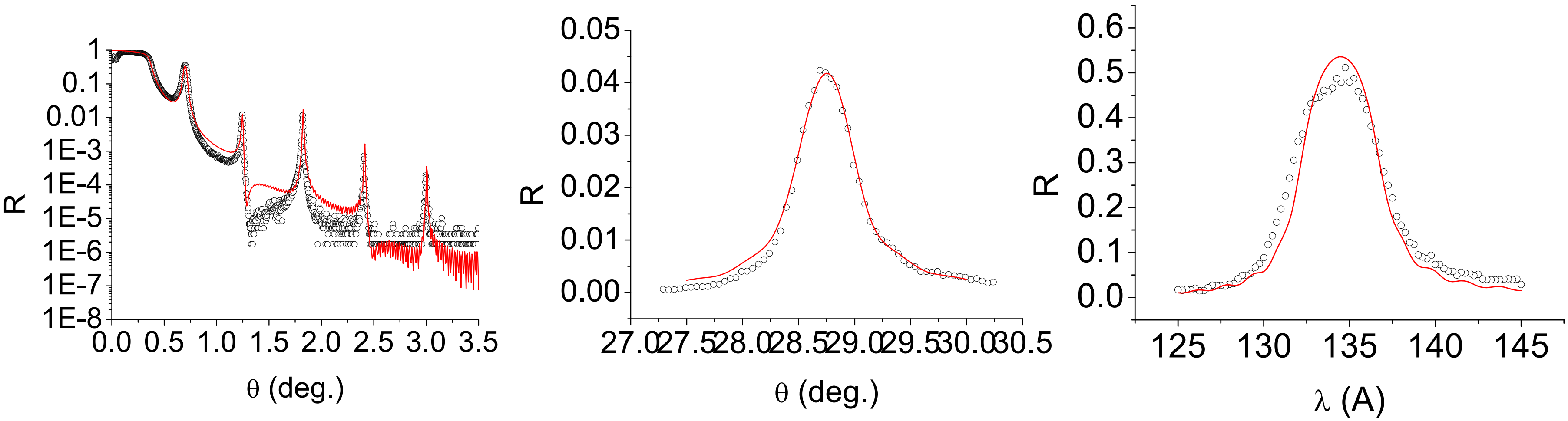
Conclusion on La/B_4C

Due to high chemical activity of La, mixing of La and B_4C films at boundaries takes place, resulting in interface degradation, causing strong decrease of reflectivity

Anti-diffusion layers of Mo, Sn and Cr were explored to weaken intermixing effects, as featured with

- **Low absorption at λ=6.7 nm**
- **Weak chemical interaction with La and B_4C**
- **Suitability of deposition by magnetron sputtering**

Mo(Cr)-La and Mo(Cr)-B_4C interfaces have exhibited a good quality in corresponding MLMs, with good reflectivity fittings for soft and hard X-rays and relatively small interface width of $\sigma \approx 0.4$-0.5nm



Mo/La MLM (N = 60) at a) λ=0.154 nm, b) λ=6.69 nm; c) λ=13.5 nm (θ = 70°).
Fitting: d=7.47 nm, β=0.45, σ=0.52 nm, ρ_{Mo} = 9.5 g/cm^3, ρ_{La} =6.0 g/cm^3.

However, application of the studied materials as anti-diffusion layers with admissible thickness of <0.3 nm has not resulted in increase of reflectivity of La/B_4C MLMs

FOM group (F. Bijkerk) reported R = 41.5% with anti-diffusion LaN/BN barriers, which enabled the demonstrated 1.2× increase of R

Current tasks

- Study and application of less chemically active layer materials
- Search for more effective anti-diffusion barriers
- Upgrade and implementation of advanced methods for treatment of interfaces
- Development of structures for 6.x nm wavelength to match optimized radiation source parameters

Acknowledgment

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